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Assignment

Atomic & Molecular Physics

PHYSICAL SCIENCES

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PHYSICAL SCIENCES (JRF-NET/GATE)

Assignment-I: Atomic Spectra

1. The linear Stark effect is possible in a hydrogen atom but not in a sodium atom because
   (a) The principal quantum number for the ground state of the sodium atom is different from that of the hydrogen atm in the ground state
   (b) Spin-orbit interaction is stronger in sodium than in hydrogen
   (c) The electronic energy levels of sodium exhibit orbital-degeneracy
   (d) The electronic energy levels of hydrogen exhibit orbital-degeneracy

2. The ground state of the deuteron is a
   (a) pure $^3S_1$ state (b) pure $^3P_1$
   (c) mixture of $^3S_1$ and $^3P_1$ (d) mixture of $^3S_1$ and $^3D_1$ states.

3. The possible values of the total angular momentum J resulting from the addition of two angular momenta $J_1 = 1$ and $J_2 = 2$ are
   (a) 1, 2 (b) 1, 3 (c) 0, 1, 2 (d) 1, 2, 3

4. For a multi-electron atom, ℓ, L and S specify the one-electron orbital angular momentum, total orbital angular momentum and total spin angular momentum, respectively. The selection rules for electric dipole transition between the two electronic energy levels, specified by ℓ, L and S are
   (a) $\Delta L = 0, \pm 1; \Delta S = 0; \Delta \ell = 0, \pm 1$ (b) $\Delta L = 0, \pm 1; \Delta S = 0; \Delta \ell = \pm 1$
   (c) $\Delta L = 0, \pm 1; \Delta S = \pm 1; \Delta \ell = 0, \pm 1$ (d) $\Delta L = 0, \pm 1; \Delta S = \pm 1; \Delta \ell = \pm 1$

5. The frequencies of lines of a line spectrum of X-ray emission depend on
   (a) The kinetic energy of the electron (b) The metal used for the anti-cathode
   (c) The spin of the electron (d) The shape of the continuous spectrum

6. Sodium atom has 11 electrons. If the sequence in which the energy levels are filled in 1s, 2s, 2p, 3s, 3p, 4s, 3d...., the ground state of sodium is:
   (a) $^3p_{1/2}$ (b) $^2p_{1/2}$ (c) $^1p_{1/2}$ (d) $^2s_{1/2}$

7. The orbital quantum numbers of two atomic electrons are $\ell_1 = 1$ and $\ell_2 = 2$. The possible values of the total angular momentum quamtum number J under LS coupling are
   (a) −1, 1 only (b) 1, 2, 3 only (c) 0, 1, 2, 3, 4 (d) −2, −1, 0, 1, 2

8. The dependence of Doppler broadened line width of a laser transition on temperature T is given by
   (a) T (b) $T^{-1/2}$ (c) $T^{1/2}$ (d) T^2

9. The continuous X-ray spectrum is the result of the
   (a) Photoelectric effect (b) Inverse photoelectric effect
   (c) Compton effect (d) Auger effect

10. The normal Zeeman effect is:
    (a) Observed only in atoms with an even number of electrons
    (b) Observed only in atoms with an odd number of electrons
    (c) A confirmation of space quantization
    (d) Not a confirmation of space quantization

11. Which of the following states exist?
    (a) $2\,^2P_1$ (b) $2\,^2P_{3/2}$ (c) $2\,^2P_{5/2}$ (d) $2\,^2P_{7/2}$

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12. The energy E of K_α X-rays emitted from targets of different atomic number Z varies as
(a) Z^2 (b) $Z^{2/3}$ (c) Z (d) $Z^{1/2}$

13. In a Stern-Gerlach experiment the atomic beam whose angular momentum state is to be determined, must travel through
(a) Homogeneous radio frequency magnetic field
(b) Homogeneous static magnetic field.
(c) Inhomogeneous static magnetic field
(d) Inhomogeneous radio frequency magnetic field

14. Under the LS coupling scheme, the possible spectral terms $^{2s+1}L_J$ for the electronic configuration 2s3s are
(a) $^2S_{1/2}, ^2P_{3/2}, ^2P_{1/2}$ (b) $^1S_0, ^3P_1$ (c) $^1S_0, ^3S_1$ (d) $^3S_0, ^3S_1$

15. Which of the following is the spectroscopic ground state for Mn^{3+} ions of electronic configuration $1s^2 2s^2 2p^6 3s^2 3p^6 3d^4$ predicted by Hund's rule?
(a) $^5D_0$ (b) $^5D_4$ (c) $^5D_3$ (d) $^5D_2$

16. The Bohr model gives the value for the ionisation potential of Li^{2+} ion as
(a) 13.6 eV (b) 27.2 eV (c) 40.8 eV (d) 122.4 eV

17. The number of hyperfine components observed in the electronic transition $^2P_{1/2} \rightarrow ^2S_{1/2}$ of an atom with nuclear spin $\frac{1}{2}$ is :
(a) 3 (b) 4 (c) 6 (d) 5

18. The Lande g-factor for the $^3P_1$ level of an atom is:
(a) 1/2 (b) 3/2 (c) 5/2 (d) 7/2

19. The total number of Zeeman components observed in an electronic transition $^2D_{5/2} \rightarrow ^2P_{3/2}$ of an atom in a weak field is:
(a) 4 (b) 6 (c) 12 (d) 10

20. In a Stern-Gerlach experiment, the magnetic field is in +z direction. A particle comes out of this experiment in $|+\hat{z}\uparrow>$ state. Which of the following statements is true?
(a) The particle has a definite value of the y-component of the spin angular momentum
(b) The particle has a definite value of the square of the spin angular momentum
(c) The particle has a definite value of the x-component of spin angular momentum.
(d) The particle has definite values of x-and y-components of spin angular momentum

21. If the wavelength of the first line of the Balmer series in the hydrogen spectrum is λ, then the wavelength of the first line of the Lyman series is :
(a) $(27/5)\lambda$ (b) $(5/27)\lambda$ (c) $(32/27)\lambda$ (d) $(27/32)\lambda$

22. The spectral term for the atom with 70% filled subshell and only S = 3/2 is :
(a) $^3P_0$ (b) $^4F_{9/2}$ (c) $^3F_{1/2}$ (d) $^4P_{1/2}$

23. The hyperfine splitting of the spectral lines of an atom is due to :
(a) The coupling between the spins of two or more electron
(b) The coupling between the spins and the orbital angular momenta of the electron
(c) The coupling between the electron spins and the nuclear spin
(d) The effect of external electromagnetic field

24. The spin-orbit coupling constant for the upper state of sodium atom which emits D lines of wave numbers 16956.2 and 16973.4 cm^{-1} is :
(a) 15 cm^{-1} (b) 11.4 cm^{-1} (c) 12.5 cm^{-1} (d) 15.1 cm^{-1}

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Common data for Q.25 and Q.26:

In the presence of an inhomogeneous weak magnetic field, spectral lines due to transitions between two sets of states were observed.

(1) $^5I_5 \rightarrow {}^5H_4$ and (2) $^2D_{5/2} \rightarrow {}^2P_{3/2}$

25. The types of Zeeman effect observed in (1) and (2) respectively are

(a) normal, normal (b) anomalous, anomalous

(c) anomalous, normal (d) normal, anomalous

26. The number of levels into which each of the above four terms split into respectively is:

(a) 6, 4, 10, 8 (b) 4, 6, 10, 12 (c) 11, 9, 6, 4 (d) 9, 5, 12, 10

27. In a hydrogen atom, the accidental or Coulomb degeneracy for the n = 4 state is:

(a) 4 (b) 16 (c) 18 (d) 32

28. The spectral terms for a certain electronic configuration are given by ^3D, ^1D, ^3P, ^1P, ^5S, ^3S. The term with the lowest energy is:

(a) ^5S (b) ^3P (c) ^3D (d) ^3S

29. The degeneracy of the spectral term ^3F is:

(a) 7 (b) 9 (c) 15 (d) 21

30. The Lande g factor for the level $^3D_3$ is:

(a) $\frac{2}{3}$ (b) $\frac{3}{2}$ (c) $\frac{3}{4}$ (d) $\frac{4}{3}$

31. The L, S and J quantum numbers corresponding to the ground state electronic configuration of Boron(Z = 5) are

(a) $L = 1, S = \frac{1}{2}, J = \frac{3}{2}$ (b) $L = 1, S = \frac{1}{2}, J = \frac{1}{2}$

(c) $L = 1, S = \frac{3}{2}, J = \frac{1}{2}$ (d) $L = 0, S = \frac{3}{2}, J = \frac{3}{2}$

32. The degeneracies of the J-states arising from the ^3P term with spin-orbit inteaction are

(a) 1, 3, 5 (b) 1, 2, 3 (c) 3, 5, 7 (d) 2, 6, 10

33. Assuming that the L-S coupling scheme is valid, the number of permited transitions from $^2P_{3/2}$ to $^2S_{1/2}$ due to a weak magnetic field is:

(a) 2 (b) 4 (c) 6 (d) 10

34. Deuteron in its ground state has a total angular momentum J = 1 and a positive parity. The corresponding orbital angular momentum L and spin S combinations are

(a) L = 0, S = 1 and L = 2, S = 0 (b) L = 0, S = 1 and L = 1, S = 1

(c) L = 0, S = 1 and L = 2, S = 1 (d) L = 1, S = 1 and L = 2, S = 1

35. The L_β line of X-rays emitted from an atom with principal quantum numbers n = 1, 2, 3, ... arises from the transition.

(a) $n = 4 \rightarrow n = 2$ (b) $n = 3 \rightarrow n = 2$ (c) $n = 5 \rightarrow n = 2$ (d) $n = 3 \rightarrow n = 2$

36. For an electron in hydrogen atom, the states are characterized by the usual quantum numbers n, l, m_l. The electric dipole transition between any two states requires that

(a) $\Delta\ell = 0, \Delta m_\ell = 0, \pm 1$ (b) $\Delta\ell = \pm 1, \Delta m_\ell = \pm 1, \pm 2$

(c) $\Delta\ell = \pm 1, \Delta m_\ell = 0, \pm 1$ (d) $\Delta\ell = \pm 1, \Delta m_\ell = 0, \pm 2$

37. The sodium doublet lines are due to transitions from $^2P_{3/2}$ and $^2P_{1/2}$ levels to $^2S_{1/2}$ level. On application of a weak magnetic field, the total number of allowed transitions becomes :

(a) 4 (b) 6 (c) 8 (d) 10

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38. In a two electron atomic system having orbital and spin angular momenta ℓ_1, ℓ_2 and s_1 s_2 respectively, the coupling strengths are defined as $\Gamma_{\ell_1\ell_2}, \Gamma_{s_1s_2}, \Gamma_{\ell_1s_1}, \Gamma_{\ell_2s_2}, \Gamma_{\ell_1s_2}$ and $\Gamma_{\ell_2s_1}$. For the jj coupling scheme to be applicable, the coupling strengths MUST satisty the condition.
(a) $\Gamma_{\ell_1\ell_2}, \Gamma_{s_1s_2} > \Gamma_{\ell_1s_1}, \Gamma_{\ell_2s_2}$ (b) $\Gamma_{\ell_1s_1}, \Gamma_{s_2s_2} > \Gamma_{\ell_1\ell_2}, \Gamma_{s_1s_2}$
(c) $\Gamma_{\ell_1s_2}, \Gamma_{\ell_2s_1} > \Gamma_{\ell_1\ell_2}, \Gamma_{s_1s_2}$ (d) $\Gamma_{\ell_1s_2}, \Gamma_{\ell_2s_1} > \Gamma_{\ell_1s_1}, \Gamma_{s_2s_2}$

39. The principal series of spectral lines of lithium is obtained by transitions between
(a) nS and 2P, n > 2 (b) nD and 2P, n > 2
(c) nP and 2S, n > 2 (d) nF and 3D, n > 3

40. In the linear Stark effect, the application of an electric field
(a) completely lifts the degeneracy of n = 2 level on hydrogen atom amd splits n = 2 level into four levels
(b) Partially lifts the degeneracy of n = 2 level on hydrogen atom amd splits n = 2 level into three levels
(c) Partially lifts the degeneracy of n = 2 level on hydrogen atom and splits n = 2 level into two levels
(d) Does not affect the n = 2 levels

41. In hyperfine interaction, there is coupling between the electron angular momentum $\bar{j}$ and nuclear angular momentum $\bar{I}$, forming resultant angular momentum $\bar{F}$. The selection rules for the corresponding quantum number F in hyperfine transitions are
(a) $\Delta F = \pm 2$ only (b) $\Delta F = \pm 1$ only (c) $\Delta F = 0, \pm 1$ (d) $\Delta F = \pm 1, \pm 2$

42. The D1 and D2 lines of Na $\left(3^2P_{1/2} \rightarrow 3^2S_{1/2}, 3^2P_{3/2} \rightarrow 3^2S_{1/2}\right)$ will split on the application of a weak magnetic field into
(a) 4 and 6 lines respectively (b) 3 lines each
(c) 6 and 4 lines respectively (d) 6 lines each

43. The allowed states for $He(2p^2)$ configuration are
(a) $^1S_0$, $^3S_1$, $^1P_1$, $^3P_{0,1,2}$ $^1D_2$ and $^3D_{1,2,3}$ (b) $^1S_0$, $^3P_{0,1,2}$ and $^1D_2$
(c) $^1P_1$ and $^3P_{0,1,2}$ (d) $^1S_0$ and $^1P_1$

44. An atomic state of hydrogen is represented by the following wave function :

$$\psi(r,\theta,\varphi) = \frac{1}{\sqrt{2}}\left(\frac{1}{a_0}\right)^{3/2}\left(1-\frac{r}{2a_0}\right)e^{-r/2a_0}\cos\theta$$

where a_0 is a constant. The quantum number of the state are:
(a) $\ell = 0, m = 0, n = 1$ (b) $\ell = 1, m = 1, n = 2$
(c) $\ell = 1, m = 0, n = 2$ (d) $\ell = 2, m = 0, n = 3$

45. In accordance with the selection rules of electric dipole transitions, the 4^3P_1 state of helium can decay by photon emission to the states
(a) $2^1S_0, 2^1P_1$ and 3^1D_2 (b) $3^1P_1, 3^1D_2$ and 3^1S_0
(c) $3^3P_2, 3^3D_3$ and 3^3P_0 (d) $2^3S_1, 3^3D_2$ and 3^3D_1

46. If an atom is in the $^3D_3$ state, the angle between its orbital and spin angular momentum vectors $\left(\bar{L} \text{ and } \bar{S}\right)$ is:

(a) $\cos^{-1}\frac{1}{\sqrt{3}}$ (b) $\cos^{-1}\frac{2}{\sqrt{3}}$ (c) $\cos^{-1}\frac{1}{2}$ (d) $\cos^{-1}\frac{\sqrt{3}}{2}$

47. The hyperfine structure of Na $\left(3^2P_{3/2}\right)$ with nuclear spin I = 3/2 has
(a) 1 state (b) 2 states (c) 3 states (d) 4 states

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48. The radial wave function of the electrons in the state of n = 1 and $\ell = 0$ in a hydrogen atom is: $R_{10} = \frac{2}{a_0^{3/2}} \exp\left(\frac{-r}{a_0}\right)$, a_0 is the Bohr radius. The most probable value of r for electron is:

(a) a_0 (b) $2a_0$ (c) $4a_0$ (d) $8a_0$

49. The last two terms of the electronic configuration of manganese(Mn) atom is $3d^5 4s^2$. The term factor of Mn^{4+} ion is :'

(a) $^4F_{1/2}$ (b) $^4D_{3/2}$ (c) $^3F_{9/2}$ (d) $^3D_{7/2}$

50. Group I lists some physical phenomena while Group II gives some physical parameters. Match the phenomena with the corresponding parameter.

Goup I		Group II
P. Doppler Broadening	1.	Moment of inertia
Q. Natural Broadening	2.	Refractive index
R. Rotational spectrum	3.	Lifetime of the energy level
S. Total interna reflection	4.	Pressure

(a) P-4, Q-3, R-1, S-2 (b) P-3, Q-2, R-1, S-4
(c) P-2, Q-3, R-4, S-1 (d) P-1, Q-4, r-2, S-3

51. Cesium has a nuclear spin of 7/2. The hyperfine spectrum of the D lines of the Cesium atom will consist of

(a) 10 lines (b) 4 lines (c) 6 lines (d) 14 lines

Common Data Q. 52 and Q.53:

Consider the Zeeman splitting of a single electron system for the 3d → 3p electric dipole transition.

52. The Zeeman spectrum is :

(a) Randomly polarized (b) Only p polarized
(c) Only s polarized (d) Both p and s polarized

53. The fine structure line having the longest wavelength will split into :

(a) 17 components (b) 10 components
(c) 8 components (d) 4 components

54. An atom with one outer electron having orbital angular momentum *l* is placed in a weak magnetic field. The number of energy levels into which the higher total angular momentum state splits, is:

(a) $2\ell + 2$ (b) $2\ell + 1$ (c) 2ℓ (d) $2\ell - 1$

55. The minimum energy required to ionize hydrogen atom from its ground state is above

(a) 13.6 eV (b) –13.6 eV (c) 0.236 eV (d) 136 eV

56. The radius of a hydrogen atom in its ground state is:

(a) 10^{-4} cm (b) 10^{-6} cm (c) 10^{-8} cm (d) 10^{-10} cm

57. The electron in a hydrogen atom with a radius equal to first Bohr radius has a velocity equal to

(a) $\frac{C}{5}$ (b) $\frac{C}{10}$ (c) $\frac{C}{137}$ (d) $\frac{C}{8}$

58. The total energy of the electron in the nth orbit of hydrogen atom is:

(a) $\frac{e^2}{4\pi\varepsilon_0 r_n}$ (b) $\frac{e^2}{4\pi\varepsilon_0 r^2_n}$ (c) $\frac{e^2}{8\pi\varepsilon_0 r_n}$ (d) $-\frac{e^2}{8\pi\varepsilon_0 r_n}$

59. The kinetic energy of an electron in atom is:

(a) Half of its potential energy (b) Twice its potential energy
(c) Equal to its potential energy (d) Thrice its potential energy

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60. The numerical value of the radius of the first orbit of hydrogen as

(a) 0.529 nm (b) 0.0529 $\overset{o}{A}$ (c) 5.29 $\overset{o}{A}$ (d) 0:0529 nm

61. The total energy of the electron in hydrogen atom is:

(a) $-(13.6/n)eV$ (b) $(13.6/n)eV$ (c) $-(13.6/n^2)eV$ (d) $(13.6/n^2)eV$

62. The ratio of frequencies of the first line of the Lyman series and the first line of Balmer series is:

(a) $\frac{27}{5}$ (b) $\frac{27}{8}$ (c) $\frac{8}{27}$ (d) $\frac{4}{27}$

63. When an electron jumps from the fourth orbit to the second orbit, one gets

(a) The first line of P fund series (b) Second line of Lyman series
(c) Second line of Paschen series (d) Second line of Balmer series

64. The Bohr formula when utilised to calculate ionization energy. He is found to yield a result higher than experimental value because of

(a) Electron- electron interaction (b) Spin orbit interaction
(c) Spin-spin interaction (d) None of above

65. The first line of the Lyman series of a ten times ionized Na atom has a wavelength of about

(a) 0.1 Å (b) 1Å (c) 10Å (d) 100Å

66. The range of frequencies of the lines of visible region in hydrogen spectrum is:

(a) $6000\times10^{14}S^{-1}$ (b) $600\times10^{14}S^{-1}$ (c) $60\times10^{14}S^{-1}$ (d) $6\times10^{14}S^{-1}$

67. The shortest wavelength of Balmer series in hydrogen spectrum is given by the equation

(a) $\frac{1}{\lambda}=R_H\left(\frac{1}{4}-\frac{1}{9}\right)$ (b) $\frac{1}{\lambda}=R_H\left(\frac{1}{2}-\frac{1}{\infty}\right)$ (c) $\frac{1}{\lambda}=R_H\left(1-\frac{1}{\infty}\right)$ (d) $\frac{1}{\lambda}=R_H\left(\frac{1}{4}-\frac{1}{\infty}\right)$

68. If v is the velocity of the electron in a stationary orbit of radius r, the orbital frequency of the electron is:

(a) $\frac{\upsilon}{2\pi r}$ (b) $\frac{\upsilon}{r}$ (c) $\frac{\upsilon}{\pi r}$ (d) $\frac{2\pi r}{\upsilon}$

69. Pauli exclusion principle state that

(a) Two electrons can have all the quantum numbers same
(b) No two electrons can have all the quantum numbers same
(c) Particles with integer and half integer spin cannot exist in the same state
(d) None of the above

70. Consider a spectal line resulting from the transition $n=2\rightarrow n=1$ in the atoms and ions given below. The shortest wavelength produced by

(a) singly ionised helium (b) hydrogen atom
(c) doubly ionised lithium (d) deuterium atom

71. One Bohr magneton is approximately

(a) $10^{23}\ Am^2$ (b) $10^{-23}\ Am^2$ (c) $10^{10}\ Am^2$ (d) $10^{-10}\ Am^2$

72. The spectroscopic symbol for the ground state of $_{13}Al$ is $^2P_{1/2}$. Under the action of a strong magnetic field (when L-S coupling can be neglected) the ground state energy level will split into

(a) 3 levels (b) 4 levels (c) 5 levels (d) 6 levels

73. The magnetic moment associated with the first orbit in hydrogen atom is given by

(a) $\frac{h}{4\pi me}$ (b) $\frac{4\pi me}{he}$ (c) $\frac{eh}{4\pi m}\times\sqrt{3}$ (d) $\frac{ehm}{4\pi}$

74. The length of the semi-major axis of an electron in an elliptical orbit is determined

(a) only by the principal quantum number
(b) only by the azimuthal quantum number
(c) both by principal quantum number and azimuthal quantum numbers
(d) none of these

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75. When the azimuthal quantum number n_ϕ is zero
(a) The ellipse reduces to a straight line (b) The ellipse reduces into a circle
(c) The ellipse reduces to a parabola (d) none of these

76. If the ϕ – dependent part of the eigen function of an electron in a hydrogen atom is $e^{2i\phi}$ the minimum pricipal– and orbital quantum numbers n and i respectively for the eigen function will be
(a) n2, 1, 1 (b) n3, 1, 2 (c) n4, 1, 3 (d) n3, 1, 1

77. Atoms with $\frac{1}{2}$ nuclear spin cannot have
(a) Hyperfine structure (b) Electric dipole interaction
(c) Fine structure (d) None of these

78. The doublets observed in alkali spectra are due to
(a) Screening of the K-electrons (b) Spin-orbit interaction of the electron
(c) Pressure of isotopes (d) None of these

79. Possible values of the total angular momentum quantum number of a single f-electron are
(a) $j=\frac{7}{2},\frac{5}{2}$ (b) $j=\pm3,2,1,0$ (c) $j=\pm\frac{7}{2}.\pm\frac{5}{2}$ (d) None of these

80. The electronic configuration $(np)^2$ can have only which one of the following term
(a) ^2D, ^3P or ^1S (b) ^1D, ^3P or ^1S (c) ^3D, ^3P or ^2S (d) None of these

81. Which of the following has the order of increasing energy?
(a) $^1D_2$, $^3D_2$, $^3F_2$ (b) $^3F_2$, $^3D_2$, $^1D_2$ (c) $^3D_2$, $^3F_2$, $^1D_2$ (d) $^1D_2$, $^3F_2$, $^3D_2$

82. In outer atomic shells of atoms 4s level is filled first by electrons than 3d level because
(a) 4s electrons are less screened from the nucleus than 3d electrons
(b) Spin-spin interaction dominates for 3d level
(c) Spin orbit intersection between the electrons in the different levels reduces energy of 4s electrons below that of 3d electrons.
(d) None of these

83. In Zeeman effect, a spectral-line, upon the application of magnetic field, splits into more than three componets because of
(a) Energy levels split into $2J+1$
(b) In magnetic field $\Delta m_J = 0, \pm1$ no longer holds
(c) Variation of Lande g-factor from one level to another
(d) None of the above

84. Two states of an atom have definite parities. An electric dipole transition between these states is:
(a) Allowed if both the states have even parity.
(b) Allowed if both the states have odd parity.
(c) Allowed if the two states have opposite parities.
(d) Not allowed unless a static electric field is applied.

Common Data for Q.85 and Q. 86.
In the presence of a weak magnetic field, atomic hydrogen undergoes the transition:

$$^2p_{1/2} \rightarrow {}^1s_{1/2}, \text{ by emission of radiation.}$$

85. The number of distinct spectral lines that are observed in the resultant Zeeman spectrum is
(a) 2 (b) 3 (c) 4 (d) 6

86. The spectral line corresponding to the transition

$$^2P_{1/2}\left(m_j=+\frac{1}{2}\right) \rightarrow {}^2S_{1/2}\left(m_j=-\frac{1}{2}\right)$$

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is observed along the direction of the applied magnetic field. The emitted electromagnetic field is:
(a) Circularly polarized (b) Linearly polarized
(c) Unpolarized. (d) Not emitted along the magnetic field direction

87. Let E_1, E_2, E_3 be the first three energy levels of a hydrogen atom. Consider the ratio $(E_3 - E_2)/(E_2 - E_1)$. Neglecting the fine structure condition this ratio is approximately equal to

(a) $\frac{27}{5}$ (b) $\frac{1}{27}$ (c) $\frac{27}{4}$ (d) $\frac{5}{27}$

88. The electronic configuration of the ground state of the Na atom is $^2S_{1/2}$. This implies that
(a) $S = 2,\ L = 0, J = 2$ (b) $S = 0, L = 1/2,\ J = 1/2$
(c) $S = 1/2,\ L = 0,\ J = 1/2$ (d) $S = 0, L = 2, J = 2$

89. A proton and a neutron are both subject to a uniform magnetic field. Which of the following is true?
(a) Both particles undergo Larmor precession because they have non-zero intrinsic magnetic moments.
(b) The neutron does not precess because its intrinsic magnetic moment is zero.
(c) The proton does not precess because its intrinsic magnetic moment is zero.
(d) Both the particles precess and the direction of the precession is the same for the two particles.

90. The degeneracy of an excited state of nitrogen atom having electronic configuration $1s^2 2s^2 2p^2 3d^1$ is:
(a) 6 (b) 10 (c) 15 (d) 150

91. If we model the electron as a uniform sphere of radius r_e spinning uniformly about an axis passing through its centre with angular momentum $L_e = \hbar/2$, and demand that the velocity of rotation at the equator connot exceed the velocity c of light in vacuum, then the minimum value of r_e is
(a) 19.2 fm (b) 0.192 fm (c) 4.8 fm (d) 1960 fm

92. The ratio of intensities of the D_1 and D_2 lines of sodium at high temperature
(a) 1:1 (b) 2:3 (c) 1:3 (d) 1:2

93. The Hydrogen α - line H_α of wavelength $\lambda = 656.3$ nm corresponds to a transition between the principal quantum states $n = 3$ and $n = 2$. The wavelength of the line H_β corresponding to the transition between $n = 4$ and $n = 2$ is
(a) 486.1nm (b) 886.0 nm (c) 437.5 nm (d) 1093.7 nm

94. For a rigid diatomic molecule, if the transition energy between two rotational levels i and j is given by $E_{i\to j}$ then $\frac{E_{2\to 1}}{E_{3\to 2}}$ is:
(a) 1/3 (b) 3/2 (c) 1/2 (d) 2/3

95. What is the maximum number of electrons with spin +1/2 in a p orbital ?
(a) 6 (b) 3 (c) 8 (d) 1

96. The shortest wavelength in the Balmer series of the Hydrogen atom occurs due to
(a) transition from the 3s to 2s (b) ionization from the 2s level
(c) ionization form th 1s level (d) transition from 2s to 1s level

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97. The Helium atom is excited into the 1s 2s configuration. The following spectral terms ^{2s+1}L are the only ones allowed

(a) $^1S, ^1P$ (b) $^1S, ^3P$ (c) $^1S, ^3S$ (d) $^2S, ^2P$

98. In the j-j coupling scheme of an atom with two electrons in the 'p' orbital, possible mj values are

(a) $\pm 1/2$ only (b) $\pm 1, 0$ (c) $\pm 3/2, \pm \frac{1}{2}$ (d) $\pm 3, \pm 2, \pm 1$

99. In the Zeeman effect the light emitted along and perpendicular to the applied magnetic field are respectively

(a) linearly and circularly polarized (b) circularly and linearly polarized
(c) both linearly polarized (d) both circularly polarized

100. For the size of the electron orbit in a hydrogen atom to be comparable to the size of a baeterium $\left(\sim 10^{-7}\,\mathrm{m}\right)$ its principal quantum number should be about

(a) 100 (b) 1000 (c) 10000 (d) 100000

101. Which of the following transitions give rise to the $K_{\alpha 1}$ line of X-ray spectra?

(a) $2\,^2S_{1/2} \rightarrow 1\,^2S_{1/2}$ (b) $2\,^2P_{1/2} \rightarrow 1\,^2S_{1/2}$ (c) $2\,^2P_{5/2} \rightarrow 1\,^2S_{1/2}$ (d) $2\,^2P_{3/2} \rightarrow 1\,^2S_{1/2}$

102. Consider a system of two spins $S_1 = 1/2, S_2 = 1/2,$ in a state with total spin zero. The correction to the energy due to the spin-spin interaction $\Delta E = A\vec{S}_1.\vec{S}_2$ is

(a) 3A/A (b) –3A/4 (c) A/4 (d) –A/4

103. The sodium D lines correspond to the transitions $^2P_{1/2} \rightarrow {}^2S_{1/2}$ and $^2P_{3/2} \rightarrow {}^1S_{1/2}$. The anomalous Zeeman effect splits the first of these lines into

(a) 2 lines (b) 4 lines (c) 1 lines (d) 3 lines

104. As a consequence of the interaction between the electron's orbital angular momentum and the nuclear spin, the $^2S_{1/2}$ electronic level of the hydrogen atom

(a) shifts up by a constant amount (b) splits into two hyperfine levels
(c) shifts down by a constant amount (d) splits into three hyperfine levels

105. A hydrogen atom is in the 2p state. To what state or states can it go by radiating a photon in an allowed transition?

(a) 1s, 2s, 3p, 3d (b) 1s, 2s, 3s, 3p (c) 2s, 3p, 3d (d) 1s, 2s

106. An atom in an excited sate $\psi_{n\ell m}$ can make a radiative transition to a state $\psi_{n'\ell'm'}$ if

(a) $\int_{-\infty}^{\infty} \psi^*_{n'\ell'm'}\, \bar{r}\, \psi_{n\ell m}\, dV \neq 0$ (b) $\int_{-\infty}^{\infty} \psi^*_{n'\ell'm'}\, \bar{r}^2\, \psi_{n\ell m}\, dV \neq 0$

(c) $\int_{-\infty}^{\infty} \psi^*_{n'\ell'm'}\, \psi_{n\ell m}\, dV = \delta_{nn'}\, \delta_{\ell\ell'}\, \delta_{mm'}$ (d) $\int_{-\infty}^{\infty} \psi^*_{n'\ell'm'}\, \bar{r}\, \psi_{n\ell m}\, dV = 0$

107. The longest wavelength in the spectral series of the Hydrogen atom occurs due to

(a) transition from $n = \infty$ to n=1 (b) ionization from 1s level
(c) transition from 2s to 1s level (d) ionization from n=100

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108. The term symbol for a particular atomic state is $^4P_{5/2}$. The values of S (spin angular momentum), L (orbital angular momentum) J (total angular momentum) of the state are

(a) $S=\frac{3}{2}, L=0, J=\frac{3}{2}$ (b) $S=\frac{1}{2}, L=1, J=\frac{3}{2}$

(c) $S=\frac{1}{2}, L=2, J=\frac{5}{2}$ (d) $S=\frac{3}{2}, L=1, J=\frac{5}{2}$

109. The ground state of sodium atom $\left(^{11}Na\right)$ is a $^2S_{1/2}$ state. The difference in energy levels arising in the presence of a weak external magnetic field B, given in terms of Bohr magneton, μ_B, is

(a) $\mu_B B$ (b) $2\mu_B B$ (c) $4\mu_B B$ (d) $6\mu_B B$

110. The terms $\{j_1, j_2\}$, arising from $2s^1\,3d^1$ electronic configuration in j – j coupling scheme are

(a) $\left\{\frac{1}{2},\frac{3}{2}\right\}_{2,1}$ and $\left\{\frac{1}{2},\frac{5}{2}\right\}_{3,2}$ (b) $\left\{\frac{1}{2},\frac{1}{2}\right\}_{1,0}$ and $\left\{\frac{1}{2},\frac{3}{2}\right\}_{2,1}$

(c) $\left\{\frac{1}{2},\frac{1}{2}\right\}_{1,0}$ and $\left\{\frac{1}{2},\frac{5}{2}\right\}_{3,2}$ (d) $\left\{\frac{3}{2},\frac{1}{2}\right\}_{2,1}$ and $\left\{\frac{1}{2},\frac{5}{2}\right\}_{3,2}$

111. Consider the Bohr model of he hydrogen atom .If α is the fine-structure constant the velocity of the electron in its lowest orbit is

(a) $\frac{C}{1+\alpha}$ (b) $\frac{C}{1+\alpha^2}$ or $(1-\alpha)c$ (c) $\alpha^2 c$ (d) αc

112. The spatial part of a two-electron state is symmetric under exchange. If $|\uparrow\rangle$ and $|\downarrow\rangle$ represent the spin-up and spin-down states respectively of each particle, the spin-part of the two-particle state is

(a) $|\uparrow\rangle|\uparrow\rangle$ (b) $|\uparrow\rangle|\downarrow\rangle$ (c) $|\downarrow\rangle|\uparrow\rangle - |\uparrow\rangle|\downarrow\rangle/\sqrt{2}$ (d) $|\downarrow\rangle|\uparrow\rangle + |\uparrow\rangle|\downarrow\rangle/\sqrt{2}$

113. The binding energy of the hydrogen atom (electron bound to proton) is 13.6eV. the binding energy of positronium (electron bound to positron) is

(a) 13.6/2eV (b) 13.6/1810eV (c) 13.6×1810eV (d) 13.6×2eV

114. The ground state electronic configuration for a carbon atom is

$$(1s)^2(2s)^2(2p)^2$$

The first excited state of this atom would be achieved by

(a) re-alignment of the electron spins within the 2p orbital

(b) transition of an electron from the 2s orbital to the 2p orbital.

(c) transition of an electron from the 2p orbital to the 3s orbital

(d) transition of an electron from 2s orbital to the 3s orbital.

115. When a pure element is vaporised and placed in a uniform magnetic field B_0, it is seen that a particular spectral line of wavelength l, corresponding to a J = 1 ® J = 0 transition, gets split into three components $\lambda, \lambda \pm \Delta\lambda$. It follows that the Lande g-factor for the transition J = 1 ® = 0 is given by

(a) $g=\frac{hc}{\mu_B B_0}\frac{\Delta\lambda^2}{\lambda}$ (b) $g=\frac{hc}{\mu_B B_0}\frac{\lambda^2}{\Delta\lambda}$ (c) $g=\frac{hc}{\mu_B B_0}\frac{\lambda}{\Delta\lambda^2}$ (d) $g=\frac{hc}{\mu_B B_0}\frac{\Delta\lambda}{\lambda}$

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116. Consider a system of three spins S_1, S_2 and S_3 each of which can take values +1 and –1. The energy of the system is given by $E = -J[S_1S_2 + S_2S_3 + S_3S_1]$, where J is a positive constant. The minimum energy and the corresponding number of spin configurations are, respectively,
(a) J and 1 (b) –3J and 1 (c) –3J and 2 (d) –6J and 22

117. The number of spectral lines allowed in the spectrum for the $3\,^2D \rightarrow 3\,^2P$ transition in sodium is _____

118. In a normal Zeeman effect experiment, spectral splitting of the line at the wavelength 643.8 nm corresponding to the transition $5\,^1D_2 \rightarrow 5\,^1P_1$ of cadmium atom is to be observed. The spectrometer has a resolution of 0.01 nM. The minimum magnetic field needed to observe this is ($m_e = 9.1 \times 10^{-31}\ kg$, $e = 1.6\times10^{-19}\ C$, $c = 3 \times 10^8\ m/s$)
(a) 0.26 T (b) 0.52 T (c) 2.6 T (d) 5.2 T

119. The electronic energy levels in a hydrogen atom are given by $E_n = -13.6/n^2$ eV. If a selective excitation to the n = 100 level is to be made using a laser, the maximum allowed frequency line-width of the laser is
(1) 6.5 MHz (2) 6.5 GHz (3) 6.5 Hz (4) 6.5 kHz

120. Which one of the following would not cause the broadening in spectral lines?
(a) Doppler effect (b) Heisenberg's uncertainty
(c) Absorption of electromagnetic radiation (d) Collisions

121. If E_H is the binding energy of the electron in the Bohr model of the Hydrogen atom, and both the charge and mass of the electron are doubled, the binding energy becomes
(a) 32 E_H (b) 2 E_H (c) 4 E_H (d) 16 E_H

122. The electronic configuration of the ground state of a nitrogen is $1s^2\,2s^2\,2p^3$. The degeneracy of this configuration is:
(a) 3 (b) 20 (c) 6 (d) 0

Statement for Linked Answer type Q. 123 and Q. 124.

Positronium is an atom formed by an electron and a positron. The mass of a positron is the same as that of an electron and its charge is equal in magnitude but opposite in sign to that of an electron. The positronium atom is thus similar to the hydrogen atom with the positron replacing the proton.

123. The binding energy of a positronium atom is:
(a) 13.6 eV (b) 6.8 eV (c) 27.2 eV (d) 3.4 eV

124. If a positronium atom makes a transition from the state with n = 3 to a state with n =2, the energy of the photon that is emitted in this transition is closest to
(a) 1.88 eV (b) 0.94 eV (c) 1.13 eV (d) 2.27 eV

125. The number of normal Zeeman splitting components of $^1P \rightarrow {}^1D$ transition is
(a) 3 (b) 4 (c) 8 (d) 9

126. A spectral line due to a transition from an electronic state p to an s state splits into three Zeeman lines in the presence of a strong magnetic field. At intermediate field strengths the number of spectral lines is
(a) 10 (b) 3 (c) 6 (d) 9

127. How much does the total angular momentum quantum number J change in the transition of $Cr(3d^6)$ atom as it ionizes to $Cr^{2+}(3d^4)$?
(a) increases by 2 (b) decreases by 2 (c) decreases by 4 (d) does not change

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ANSWER KEY

1. (d)	2. (d)	3. (d)	4. (a)	5. (b)	6. (d)	7. (c)
8. (c)	9. (b)	10. (c)	11. (b)	12. (a)	13. (c)	14. (c)
15. (a)	16. (d)	17. (a)	18. (b)	19. (c)	20. (b)	21. (b)
22. (b)	23. (c)	24. (d)	25. (b)	26. (c)	27. (d)	28. (a)
29. (d)	30. (d)	31. (b)	32. (a)	33. (c)	34. (c)	35. (a)
36. (c)	37. (d)	38. (b)	39. (c)	40. (b)	41. (c)	42. (a)
43. (b)	44. (c)	45. (d)	46. (a)	47. (d)	48. (a)	49. (a)
50. (a)	51. (a)	52. (d)	53. (b)	54. (b)	55. (a)	56. (c)
57. (c)	58. (d)	59. (a)	60. (d)	61. (c)	62. (a)	63. (d)
64. (a)	65. (c)	66. (d)	67. (d)	68. (a)	69. (b)	70. (c)
71. (b)	72. (c)	73. (c)	74. (c)	75. (a)	76. (b)	77. (b)
78. (b)	79. (a)	80. (b)	81. (b)	82. (c)	83. (c)	84. (c)
85. (c)	86. (a)	87. (d)	88. (c)	89. (a)	90. (d)	91. (a)
92. (d)	93. (d)	94. (d)	95. (a)	96.(b)	97. (c)	98. (d)
99. (b)	100. (a)	101. (d)	102. (b)	103. (b)	104. (b)	105. (d)
106. (a)	107. (d)	108. (d)	109. (b)	110. (b)	111. (d)	112. (d)
113. (a)	114. (a)	115. (d)	116. (c)	117. (3)	118. (b)	119. (b)
120. (c)	121. (a)	122. (b)	123. (b)	124. (b)	125. (a)	126. (a)
127. (c)						

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PHYSICAL SCIENCES (JRF-NET/GATE)

Assignment-II: Molecular Spectra

1. A stable H_2 molecule is possible because .
   (a) The electronic ground state is spin triplet
   (b) The magnitude of the electronic charge density is maximal in the internuclear region
   (c) The electronic charge density is depleted in the internuclear region
   (d) Of strong spin-orbit interaction in the molecule.

2. The energy separation between two consecutive stokes lines in Raman Scattering depends on
   (a) Energy separation between vibrational levels in the excited state
   (b) Wavelength of the incident light
   (c) Energy separation between vibrational levels in the ground state
   (d) Intensity of the incident light

3. Typical energy of the rotational modes in a polyatomic molecule like NH_3 is:
   (a) 10^6eV (b) 10^3eV (c) 10^4eV (d) 1 eV

4. There is no infrared absorption for nitrogen molecule because:
   (a) Its polarizability is zero (b) It has no vibrational levels
   (c) It has no rotational levels (d) Its dipole moment is zero

5. The vibrational constants ω_0 and $\omega_0 x_0$ of HCl are 2937.5 cm^{-1} and 51.6 cm^{-1}. The first Raman stokes line will be observed at (in cm^{-1})
   (a) 2989.1 (b) 2885.9 (c) 2834.3 (d) 3040.7

6. The intensity of the electronic 0-0 band of a diatomic molecule is very intense when the minimum of the potential curve for the upper electronic state lies (here r is the internuclear distance).
   (a) at the same value r as that of the lower potential curve
   (b) at a smaller value of r than that of the lower potential curve
   (c) at a larger value of r than that of the lower potential curve
   (d) above the dissociation level of the lower potential curve

7. Which one of the following molecules does not exhibit a rotational spectrum?
   (a) H_2 (b) CO (c) HCl (d) HBr

8. Resonance (NMR, ESR etc.) studies in solids provide information about
   (a) The electronic structure of single defects
   (b) The motion of the spin or of the surrounding
   (c) Collective spin excitations
   (d) Internal magnetic fields sampled by the spin

9. Infrared absorption can be observed in which of the following molecules?
   (a) N_2 (b) O_2 (c) HCl (d) C_2

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10. The pure rotational levels of a molecule in the far-infrared region follows the formula $F(J) = BJ(J+1)$, where F(J) is the energy of the rotational level with quantum number J and B is the rotational constant. The lowest rotational energy gap in rotational Raman spectrum is :
(a) 2B (b) 4B (c) 6B (d) 8B

11. The rotational partition function for a diatomic molecule of moment of inertia I at a temperature T is given by
(a) $\frac{Ik_BT}{\hbar^2}$ (b) $\frac{2Ik_BT}{\hbar^2}$ (c) $\frac{3Ik_BT}{\hbar^2}$ (d) $\frac{Ik_BT}{2\hbar^2}$

12. The vibrational spectrum of a molecule exhibits a strong line with P and R branches at a frequency u_1 and a weaker line at a frequency u_2. The frequency u_3 isnot shown up. Its vibrational Raman spectrum shows a strongly polarized line at frequency u_3 and no feature at u_1 and u_2
(a) The molecule could be linear
(b) The molecule lacks a center of inversion
(c) u_1 arises from a symmetric stretching mode
(d) u_3 arises from a bending mode

13. Three values of rotational energies of molecules are given below in different units
P: $10\ cm^{-1}$ Q: 10^{-23} J R: 10^4 MHz
Choose the correct arrangement in the increasing order of energy
(a) P, Q, R (b) R, Q, P (c) R, P, Q (d) Q, R, P

14. Consider the following statements about molecular spectra
P: CH_4 does not give pure rotational Raman lines
Q: SF_6 could be studied by rotational Raman spectroscopy
R: N_2 shows infrared absorption spectrum
S: CH_3CH_3 shows vibrational Raman and infrared absorptin lines
T: H_2O_2 shows pure rotational spectrum
Choose the right combination of correct statements
(a) P and Q (b) P, R and T (c) P, S and T (d) Q and R

15. All vibrations producing a change in the electric dipole moment of a molecule yield
(a) Raman spectra (b) Infrared spectra
(c) Ultra-violet spectra (d) X-ray spectra

16. Consider the pure rotational spectrum of a diatomic rigid rotor, The separation between two consecutive lines $(\Delta\bar{V})$ in the spectrum
(a) Is directly proportional to the moment of inertial of the rotor
(b) In inversely proportional to the moment of inertia of the rotor
(c) Depends on the angular momentum
(d) Is directly proportional to the square of the interatomic separation

17. Light of wavelength 1.5 μm incident on a material with a characteristic Raman frquency of 20×10^{12} Hz results in a stokes-shifted line of wavelength $\left[\text{Given : } c = 3\times10^8\ m.s^{-1}\right]$
(a) 1.47 μm (b) 1.57 μm (c) 1.67 μm (d) 1.77 μm

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18. Match the following and choose the correct combination

Group-I	Group-2
P. Atomic configuration $1s^2 2s^2 2p^6 3s^2 3p^6$	1. Na
Q. Strongly electropositive	2. Si
R. Strongly electronegative	3. Ar
S. Covalent bonding	4. Cl

(a) P-1, Q-2, R-3, S-4 (b) P-3, Q-2, R-4, S-1
(c) P-3, Q-1, R-4, S-2 (d) P-3, Q-4, R-1, S-2

19. In a Raman scattering experiment, light of frequency u from a laser is scattered by diatomic molecules having the moment of inertia I. the typical Raman shifted frequency depends on
(a) u and I (b) only u (c) only I (d) neither u nor I

20. For a diatomic molecule with the vibrational quantum number n and rotational quantum number J, the vibrational level spacing $\Delta E_n = E_n - E_{n-1}$ and the rotational level spacing $\Delta E_J = E_J - E_{J-1}$ are approximately
(a) $\Delta E_n = \text{constant}, \Delta E_J = \text{constant}$ (b) $\Delta E_n = \text{constant}, \Delta E_J \propto J$
(c) $\Delta E_n \propto n, \Delta E_J \propto J$ (d) $\Delta E_n \propto n, \Delta E_J \propto J^2$

21. The typical wavelengths emitted by diatomic molecules in purely vibrational and purely rotational transitions are respectively in the region of
(a) Infrared and visible (b) Visible and infrared
(c) Infrared and microwave (d) Microwave and infrared

22. In the microwave spectrum of identical rigid diatomic molecules, the separation between the spectral lines is recorded to be 0.7143 cm^{-1}. The moment of inertia of the molecule, in kg m^2, is :
(a) 2.3×10^{-36} (b) 2.3×10^{-40} (c) 7.8×10^{-42} (d) 7.8×10^{-46}

23. A vibrational-electronic spectrum of homonuclear binary molecules, involving electronic ground state ε'' and excited ε', exhibits a continuum at $\bar{\upsilon}\ cm^{-1}$. If the total energy of the dissociated atoms in the excited state exceeds the total energy of the dissociated atoms in the ground state by $E_{ex}\ cm^{-1}$, then dissociation energy of the molecule in the ground state is :
(a) $(\bar{\upsilon}+E_{ex})/2$ (b) $(\bar{\upsilon}-E_{ex})/2$ (c) $(\bar{\upsilon}-E_{ex})$ (d) $\sqrt{(\bar{\upsilon}^2-E_{ex}^2)}$

24. Match the following:

P: Franck-Hertz experiment	1. Electronic excitation of molecules
Q: Hartree-Fock method	2. Wave function of atom
R: Stern-Gerlach experiment	3. Spin angular momentum of atoms
S: Franck-Condon principle	4. Energy levels in atoms

(a)	(b)	(c)	(d)
P-4	P-1	P-3	P-4
Q-2	Q-4	Q-2	Q-1
R-3	R-3	R-4	R-3
S-1	S-2	S-1	S-2

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25. The allowed rotational energy levels of a rigid hetero-nuclear diatomic molecule are expressed as $\varepsilon_J = BJ(J+1)$, where B is the rotational constant and J is a rotational quantum number.
In a system of such diatomic molecules of reduced mass μ, some of the atoms of one element are replaced by a heavier isotope, such that the reduced mass is changed to $1.05\,\mu$. In the rotational spectrum of the system, the shift in the spectral line, corresponding to a transition $J = 4 \rightarrow J = 5$, is :
(a) 0.475B (b) 0.50 B (c) 0.95 B (d) 1.0 B

26. The number of fundamental vibrational modes of CO_2 molecule is :
(a) Four: 2 are Raman active and 2 are infrared active
(b) Four: 1 is Raman active and 3 are infrared active
(c) Three: 1 is Raman active and 2 are infrared active
(d) Three: 2 are Raman active and 1 is infrared active

27. (Rotational spectra) Three consecutive absorption lines at $64.275\ cm^{-1}$, $77.130\ cm^{-1}$ and $89.985\ cm^{-1}$ have been observed in a microwave spectrum for a linear rigid diatomic molecule. The moments of inertia I_A and I_B are (I_A is with respect to the bond axis passing through the centre of mass and I_B is with respect to an axis passing through the centre of mass and perpendicular to bond axis)
(a) both equal to $\frac{\hbar^2}{12.855hc}$ gm cm^2 (b) zero and $\frac{\hbar^2}{12.855hc}$ gm cm^2
(c) both equal to $\frac{\hbar^2}{6.427hc}$ gm cm^2 (d) zero and $\frac{\hbar^2}{6.427hc}$ gm cm^2

28. A pure rotational Raman spectrum of a linear diatomic molecule is recorded using electromagnetic radiation of frequency u_e. The frequency of two consecutive stokes lines are :
(a) $\upsilon_e - 10B, \upsilon_e - 14B$ (b) $\upsilon_e - 2B, \upsilon_e - 4B$
(c) $\upsilon_e + 10B, \upsilon_e + 14B$ (d) $\upsilon_e + 2B, \upsilon_e + 4B$

29. Which one of the following statement is INCORRECT in vibrational spectroscopy with anharmonicity?
(a) The selection rule for vibrational spectroscopy is $\Delta v = \pm 1, \pm 2, ...$
(b) Anharmonicity leads to multiple absorption lines
(c) The intensities of hot band lines are stronger than the fundamental absorption.
(d) The frequencies of hot band lines are smaller than the fundamental absorption.

30. The molecular spectra of two linear molecules O-C-O and O-C-S are recorded in the microwave region. Which one of the following statement is correct?
(a) Both the molecules would show absorption lines
(b) Both the molecules woulb not show absorption lines
(c) O-C-O would show absorption lines, but not O-C-S.
(d) O-C-S would show absorption lines, but not O-C-O.

31. The separation between the first stokes and corresponding anti-stokes lines of the rotational Raman spectrum in terms of the rotational constant, B is :
(a) 2B (b) 4B (c) 6B (d) 12B

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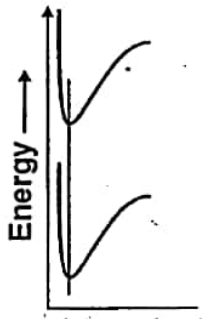
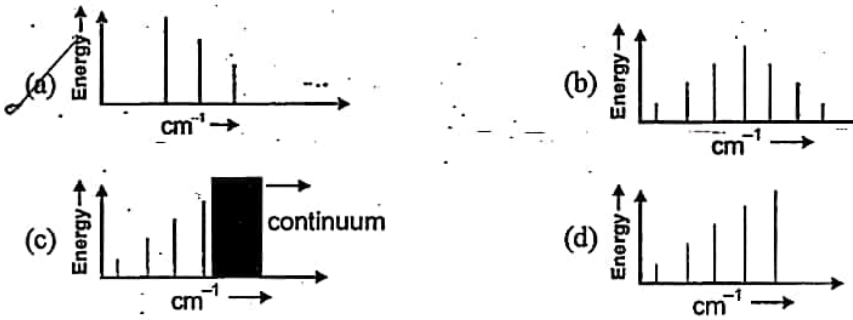
32. In a diatomic molecule, the internuclear separation of the ground and first excited electronic state are the same as shown in the figure. If the molecule is initially in the lowest vibrational state of the ground state, then the absorption spectrum will appear as





33. The spectrum of radiation emitted by a black body at a temperature 1000 K peaks in the
(a) Visible range of frequencies (b) Infrared range of frequencis.
(c) Ultraviolet range of frequencies (d) Microwave range of frequencies.

34. The three principal moments of inertia of a methanol (CH_3OH) molecule have the property $I_x = I_y = I$ and $I_z \neq I$. The rotational energy eigenvalues are

(a) $\frac{\hbar^2}{2I}\ell(\ell+1)+\frac{\hbar^2 m_l^2}{2}\left(\frac{1}{I_z}-\frac{1}{I}\right)$ (b) $\frac{\hbar^2}{2I}\ell(\ell+1)$

(c) $\frac{\hbar^2 m_l^2}{2}\left(\frac{1}{I_z}-\frac{1}{I}\right)$ (d) $\frac{\hbar^2}{2I}\ell(\ell+1)+\frac{\hbar^2 m_l^2}{2}\left(\frac{1}{I_z}+\frac{1}{I}\right)$

35. Match the typical spectra of stable molecules with the corresponding wave-number rnage

1. Electronic spectra.	i. 10^6 cm^{-1} and above
2. Rotational spectra	ii. $10^5 - 10^6$ cm^{-1}
3. Molecular dissociation	iii. $10^0 - 10^2$ cm^{-1}

(a) 1–ii, 2–i, 3–iii (b) 1–ii, 2–iii, 3–i
(c) 1–iii, 2–ii, 3–i (d) 1–i, 2–ii, 3–iii.

36. CO_2 molecule has the first few energy levels uniformly separated by approximately 2.5 meV. At a temperature of 300 K, the ratio of the number of molecules in the 4th excited state to the number in the 2nd excited state is about.
(a) 0.5 (b) 0.6 (c) 0.8 (d) 0.9

37. You are shown a spectrum consisting of a series of equally spaced lines. This could be
(a) The rotational spectrum CO. (b) The vibrational spectrum of N_2.
(c) The NMR spectrum of CH_4 (d) The Mossbauer spectrum of Fe_3O_4.

38. The rotational energy levels of a rigid diatomic molecules are given by $E_J = B_e J(J+1)$ where J is the rotational quantum number and B_e is the constant. The rotational absorption spectrum of the molecules therefore consists of
(a) One resonance line
(b) Lines that are equally spaced.
(c) Lines where the spacing increases with frequency
(d) Lines where the spacing decreases with frequency.

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39. Consider the CO molecule as a diatomic rigid rotor with a bond length of 1.12 Å. The reduced mass of the system is obtained from the atomic masses of C and O. The rotational energies are defined in terms of B(the rotational constant) and J (the rotational quantum number). If ν_1 and ν_2 denotes the frequency of the first rotational resonance lines for the moleules $^{12}C\,^{16}O$ and $^{13}C\,^{18}O$ respectively, their ratio ν_1 / ν_2 is approximately.
(a) 1.5 (b) 1.1 (c) 0.9 (d) 1.01

40. The strongest three lines in the emission spectrum of an interstellar gas cloud are found to have wavelengths $\lambda_0, 2\lambda_0$ and $6\lambda_0$ respectively, where λ_0 is a known wavelength. From this we can deduce that the radiating particles in the cloud behave like
(a) Free particles (b) Particles in a box
(c) Harmonic oscillators (d) Rigid rotators

41. A laser operating at 500 nm is used to excite a molecule. If the Stokes line is observed at 770 cm^{-1}, the approximate positions of the Stokes and the anti-Stokes lines are
(a) 481.5 nm and 520 nm (b) 481.5 nm and 500 nm
(c) 500 nm and 520 nm (d) 500 nm and 600 nm

42. Which of the diatomic molecules H_2, HD, D_2 and HT has the highest vibrational frequency?
(a) HT (b) D_2 (c) HD (d) H_2

43. If a molecule has a centre of symmetry then
(a) Raman active vibrations are infrared active
(b) Raman active vibrations are infrared inactive and vice versa
(c) some, but not all, of the Raman active vibrations are infrared active
(d) all vibrations are Raman and infrared inactive.

44. In which of the following pairs do both molecules exhibit rotational spectra?
(a) CCl_4 and HF (b) CCl_4 and O_2 (c) HCN and HF (d) HCN and CCl_4

45. The sharpest sepctrum lines in the microwave rotational spectrum are observed when the sample is a
(a) solid (b) liquid (c) liquid crystal (d) gas

46. The unequal spacing in the vibrational energy levels of a diatomic molecule would be due to the
(a) Presence of anharmonic terms in the potential energy.
(b) Finite mass of the nuclei.
(c) Frank-Condon principle.
(d) Harmonic nature of the potential energy.

47. Match the typical spectroscopic regions specified in **Group I** With the corresponding type of transitions in **Group II.**

Group I	**Group II**
(P) Infra-red region	(i) electronic transitions involving valence electrons
(Q) Ultraviolet- visible region	(ii) nuclear transitions
(R) X-ray region	(iii) vibrational transitions of molecules
(S) γ -ray region	(iv) transitions involving inner shell electrons

(a) (P,i);(Q,iii);(R,ii);(S,iv) (b) (P,ii);(Q,iv);(R,i);(S,iii)
(c) (P,iii);(Q,i);(R,iv);(S,ii) (d) (P,iv);(Q,i);(R,ii);(S,iii)

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48. The equilibrium vibration frequency for an oscillator observed at $2990\,cm^{-1}$. The ratio of the frequencies corresponding to the first and the fundamental spectral lines is 1.96. Considering the oscillator to be anharmonic, the anharmonicity constant is
(a) 0.005 (b) 0.02 (c) 0.05 (d) 0.1

49. NET The first absorption spectrum of $^{12}C^{16}O$ is at $3.842\,cm^{-1}$ while that of $^{13}C^{16}O$ is at $3.673\,cm^{-1}$. The ratio of their moments of inertia is
(a) 1.851 (b) 1.286 (c) 1.046 (d) 1.038

50. The spacing between vibrational energy levels in CO molecule is found to be 8.441×10^{-2} eV. Given that the reduced mass of CO is 1.14×10^{-26} kg, Planck's constant is 6.626×10^{-34} Js and $1eV = 1.6 \times 10^{-19}J$. The force constant of the bond is CO molecule is
(a) 1.87 N/m (b) 18.7 N/m (c) 187 N/m (d) 1870 N/m

51. Consider the hydrogen deuterium molecule HD. If the mean distance between the two atoms is 0.08 nm and the mass of the hydrogen atom is 938 MeV/c^2, then the energy difference ΔE between the two lowest rotational states is approximately
(1) 10^{-1}eV (2) 10^{-2}eV (3) 2×10^{-2}eV (4) 10^{-3}eV

52. Raman effect is suppressed in
(a) semiconductors (b) dielectrics (c) metals (d) insulators

53. The moment of inertia of a rigid diatomic molecule A is 6 times that of another rigid diatomic molecule B. If the rotational energies of the two molecules are equal, then the corresponding values of the rotational quantum numbers J_A and J_B are
(a) $J_A = 2, J_B = 1$ (b) $J_A = 3, J_B = 1$ (c) $J_A = 5, J_B = 0$ (d) $J_A = 6, J_B = 1$

ANSWER KEY

1. (b)	**2. (c)**	**3. (c)**	**4. (d)**	**5. (b)**	**6. (a)**	**7. (a)**
8. (d)	**9. (c)**	**10. (a)**	**11. (c)**	**12. (a, c)**	**13. (b)**	**14. (c)**
15. (b)	**16. (b)**	**17. (c)**	**18. (c)**	**19. (c)**	**20. (b)**	**21. (c)**
22. (d)	**23. (c)**	**24. (a)**	**25. (a)**	**26. (b)**	**27. (b)**	**28. (a)**
29. (c)	**30. (d)**	**31. (d)**	**32. (a)**	**33. (c)**	**34. (a)**	**35. (b)**
36. (c)	**37. (a)**	**38. (b)**	**39. (b)**	**40. (d)**	**41. (a)**	**42. (c)**
43. (c)	**44. (c)**	**45. (c)**	**46. (a)**	**47. (c)**	**48. (b)**	**49. (c)**
50. (c)	**51. (b)**	**52. ( )**	**53. (b)**			

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PHYSICAL SCIENCES (JRF-NET/GATE)

Assignment-III: Laser Physics

1. The number of photons emitted per second from a 1 Watt Ar-ion laser operating at 488.0 nm is approximately

   (a) 10.23×10^{19} (b) 2.46×10^{18} (c) 10.23×10^{17} (d) 2.46×10^{15}

2. Spectral line width of the He-Ne laser is 0.01 nm and the cross sectional area of the beam is 0.01 cm^2. If the output power is 1 milli Watt, the radiation intensity per unit wavelength (in Watt/cm^3) is:

   (a) 10^{10} (b) 10^{8} (c) 10^{-8} (d) 10^{-10}

3. A laser beam emerging from a laser tube operating at 800 nm has a cross sectional diameter of 2 mm. The diameter of the beam at a distance of 1 km is approximately given by

   (a) 10 nm (b) 8 cm (c) 80 cm (d) 10 m

4. A laser beam of wavelength 600 nm with a cricular cross section having a radius of 10 mm falls normally on a lens of radius 20 mm and focal length 10 cm. The radius of the focussed spot is approximately

   (a) 0.3 μm (b) 0.6 μm (c) 3.0 μm (d) 6.0 μm

5. A three level system of atoms has N_1 atoms in level E_1, N_2 in level E_2, and N_3 in level E_3 ($N_2 > N_1 > N_3$ and $E_1 < E_2 < E_3$). Laser emission is possible betwen the levels

   (a) $E_3 \rightarrow E_1$ (b) $E_2 \rightarrow E_1$ (c) $E_3 \rightarrow E_2$ (d) $E_2 \rightarrow E_3$.

6. Which one of the following electronic transitions in Neon is NOT responsible for LASER action in a helium-neon laser?

   (a) $6s \rightarrow 5p$ (b) $5s \rightarrow 4p$ (c) $5s \rightarrow 3p$ (d) $4s \rightarrow 3p$

7. In a He-Ne laser, the laser transition takes place in

   (a) He only (b) Ne only
   (c) Ne first, then in He. (d) He first, then in Ne

8. The coherence length of laser light is :
   (a) Directly proportional to the length of the active medium
   (b) Directly proportional to the width of the spectral line
   (c) Inversely proportional to the width of the spectral line
   (d) Inversely proportional to the length of the active lasing medium

9. When the refractive index m of the active medium changes by Dm in a laser resonator of length L, the change in the spectral spacing between the longitudinal modes of the laser is (c is the speed of light in free space)

   (a) $\frac{c}{2(\mu+\Delta\mu)L}$ (b) $\frac{c}{2\Delta\mu L}$ (c) $\frac{c}{2L}\frac{\Delta\mu}{\mu(\mu+\Delta\mu)}$ (d) zero

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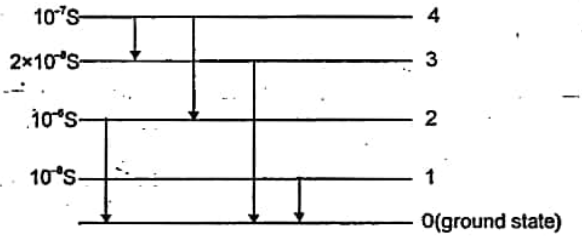
10. Five energy levels of a system including the ground state are shown below. Their lifetimes and the allowed electric dipole transitions are also marked.



Which one of the following transitions is the most suitable for a continuous wave (CW) laser?

(a) $1 \rightarrow 0$ (b) $2 \rightarrow 0$ (c) $4 \rightarrow 2$ (d) $4 \rightarrow 3$

11. The population inversion in a two level laser material CANNOT be achieved by optical pumping because
(a) The rate of upward transitions is equal to the rate of downward transitions.
(b) The upward transitions are forbidden but downward transitions are allowed.
(c) The upward transitions are allowed but downward transitions are forbidden.
(d) The spontaneous decay rate of the higher level is very low.

12. A collection of N atoms is exposed to a strong resonant electromagnetic radiation with N_g atoms in the ground state and Ne atoms in the excited state, such that $N_g + N_e = N$. This collection of two–level atoms will have the following population distribution.

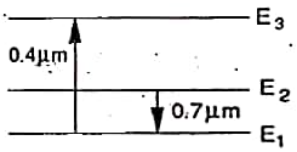
(a) $N_g << N_e$ (b) $N_g >> N_e$ (c) $N_g \approx N_e \approx N/2$ (d) $N_g - N_e \approx N/2$

13. For an atom with two energy levels placed in a cavity containing blackbody radiation, the ratio of the probabilities for spontaneous emission and stimulated emission is given by $\frac{A}{B} = \frac{8\pi\nu^3}{c^3}$, where A and B are the corresponding Einstein coefficients and ν is the frequency of the photon emitted. The probability of spontaneous emission.
(a) Is independent of the energy difference between the two levels.
(b) Increases with the energy difference between the two levels.
(c) Decreases with the energy difference between the two levels.
(d) Is zero.

14. The mirrors of a laser cavity are separated by a distance L. If T is the time taken by the light to travel from one mirror to the other and back, the mode separation is:

(a) $\frac{1}{T}$ (b) $\frac{2}{T}$ (c) $\frac{1}{2T}$ (d) $\frac{1}{\sqrt{2}\,T}$

15. Consider the energy level diagram (as shown in the figure below) of a typical three level ruby laser system with 1.6×10^{19} Chromium ions per cubic centimeter. All the atoms excited by the 0.4 μm radiation decay rapidly to level E_2 which has a lifetime $\tau = 3ms$



A. Assuming that there is no radiation of wavelength 0.7 μm present in the pumping cycle and that the pumping rate is R atoms per cm^3, the population density in the level N_2 builds up as:

(a) $N_2(t) = R\tau\left(e^{t/\tau} - 1\right)$ (b) $N_2(t) = R\tau\left(1 - e^{-t/\tau}\right)$

(c) $N_2(t) = \frac{Rt^2}{\tau}\left(1 - e^{-t/\tau}\right)$ (d) $N_2(t) = Rt$

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B. The minimum pump power required (per cubic centimeter) to bring the system to transparency, i.e. zero gain, is

(a) 1.52 kW (b) 2.64 kW (c) 0.76 kW (d) 1.32 kW

16. The central wavelength of a $0.6\,\mu m$ wavelength laser corresponds to the m^{th} cavity mode of a resonator cavity of length 6 cm. The mode number m is

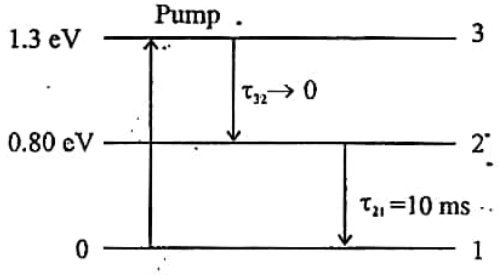
(a) 1000 (b) 2×10^4 (c) 2×10^5 (d) 200

17. A collection of spin-1/2, particles is in thermal equilibrium at temperature T in an applied magnetic field. The ratio of the population of the two allowed energy levels with separation ΔE is

(a) $\frac{N_{upper}}{N_{lower}} = \exp\left(\frac{-\Delta E}{k_B T}\right)$ (b) $\frac{N_{upper}}{N_{lower}} = 1-\exp\left(\frac{-\Delta E}{k_B T}\right)$

(c) $\frac{N_{upper}}{N_{lower}} = \exp\left(\frac{-2\Delta E}{k_B T}\right)$ (d) $\frac{N_{upper}}{N_{lower}} = 1+\exp\left(\frac{-\Delta E}{k_B T}\right)$

18. The typical energy level diagram for Erbium ions in a glass is shown below.



For an Erbium ion concentration of ρ ions/cm^3, the pump power needed for population inversion is

(a) $80\,\rho$ eV / m^3s (b) $40\,\rho$ eV / m^3s (c) $130\,\rho$ eV / m^3s (d) $65\,\rho$ eV / m^3s

19. In which of the following lasers can the wavelength not be tuned?

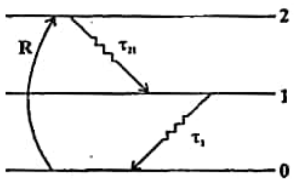
(a) semiconductor laser (b) Dye laser
(c) Ti: Sapphire laser (d) Ruby laser

20. Consider a hydrogen atom undergoing a $2P \rightarrow 1S$ transition. The lifetime t_{sp} of the 2P state for spontaneous emission is 1.6 ns and the energy difference between the levels is 10.2 eV. Assuming that the refractive index of the medium $n_0 = 1$, the ratio of the Einstein coefficients for stimulated emission $B_{21}(\omega)/A_{21}(\omega)$ is given by

(a) 0.683×10^{12} $m^3J^{-1}s^{-1}$ (b) 0.146×10^{-12} J s m^{-3}

(c) 6.83×10^{12} m^3 J^{-1} s^{-1} (d) 1.463×10^{-12} J s m^{-3}

21. Consider the energy level diagram shown below, which corresponds to the molecular nitrogen laser.



If the pump rate R is 10^{20} atoms $cm^{-3}s^{-1}$ and the decay routes are as shown with $\tau_{21} = 20$ ns and $\tau_1 = 1\,\mu s$, the equilibrium populations of states 2 and 1 are, respectively,

(a) 10^{14} cm^{-3} and 2×10^{12} cm^{-3} (b) 2×10^{12} cm^{-3} and 10^{14} cm^{-3}
(c) 2×10^{12} cm^{-3} and 2×10^{6} cm^{-3} (d) zero and 10^{20} cm^{-3}.

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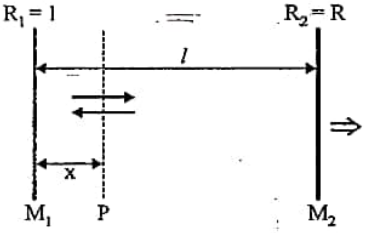
22. Consider a He-Ne laser cavity consisting of two mirrors of reflectivities $R_1 = 1$ and $R_2 = 0.98$. The mirrors are separated by a distance $d = 20$ cm and the medium in between has a refractive index $n_0 = 1$ and absorption coefficient $\alpha = 0$. The values of the separation between the modes $\delta\nu$ and the width $\Delta\nu_p$ of each mode of the laser cavity are:

(a) $\delta\nu = 75$ kHz, $\Delta\nu_p = 24$ kHz (b) $\delta\nu = 100$ kHz, $\Delta\nu_p = 100$ kHz

(c) $\delta\nu = 750$ MHz, $\Delta\nu_p = 2.4$ MHz (d) $\delta\nu = 2.4$ MHz, $\Delta\nu_p = 750$ MHz

23. Consider the laser resonator cavity shown in the figure.
If I_1 is the intensity of the radiation at mirror M_1 and α is the gain coefficient of the medium between the mirrors, then the energy density of photons in the plane P at a distance x from M_1 is



(a) $(I_1/c)e^{-\alpha x}$ (b) $(I_1/c)e^{\alpha x}$ (c) $(I_1/c)(e^{\alpha x}+e^{-\alpha x})$ (d) $(I_1/c)e^{2\alpha x}$

24. Two monochromatic sources, L_1, and L_2, emit light at 600 and 700 nm, respectively. If their frequency bandwidths are 10^{-1} and 10^{-3} GHz, respectively, then the ratio of linewidth of L_1 and L_2 is approximately
(a) 100 : 1 (b) 1 : 85 (c) 75 : 1 (d) 1 : 75

25. A gas laser cavity has been designed to operate at $\lambda = 0.5\mu$m with a cavity length of 1m. With this set-up, the frequency is found to be larger than the desired frequency by 100 Hz. The change in the effective length of the cavity required to retune the laser is
(a) -0.334×10^{-12} m (b) 0.334×10^{-12} m
(c) 0.167×10^{-12} m (d) -0.167×10^{-12} m

26. A beam of atoms moving in a certain direction can be slowed down if they absorb photons from a laser beam moving in the opposite direction and subsequently spontaneously emit photons isotropically. For a beam of Sodium atoms (mass number A = 23) with speed 600 ms^{-1}, if a laser beam of wavelength 589 nm is used, the number of such absorption and emission cycles needed to bring a Sodium atom to rest would be approximately.
(a) 1.3×10^5 (b) 1.3×10^4 (c) 2.1×10^3 (d) 2.1×10^4

27. The emission wavelength for the transition ${}^1D_2 \rightarrow {}^1F_3$ is 3122 Å. The ratio of populations of the final to the initial states at a temperature 5000 K is ($h = 6.626\times10^{-34}$ J.s, $c = 3\times10^8$ m/s, $k_B = 1.380\times10^{-23}$ J/K)
(a) 2.03×10^{-5} (b) 4.02×10^{-5} (c) 7.02×10^{-5} (d) 9.83×10^{-5}

ANSWER KEY

1. (b)	2. (b)	3. (c)	4. (a)	5. (b)	6. (c)	7. (b)
8. (c)	9. (c)	10. (b)	11. (a)	12. (c)	13. (a)	14. (a)
15_A(b)	15_B(a)	16. (b)	17. (d)	18. (c)	19.(d)	20. (a)
21. (b)	22. (c)	23. ( )	24. (c)	25. ( )	26. ( )	27. (c)

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PHYSICAL SCIENCES (JRF-NET/GATE)

Assignment-IV: Miscelleneous

1. A line arising from a transition of an atom from an excited state to the ground state has a width D of 0.5 cm^{-1}. If the width is almost entirely due to the width of the initial state, the lifetime of this state will be closest to :
(a) 6×10^{-12} sec (b) 6×10^{-15} sec (c) 6×10^{-9} sec (d) 6×10^{-17} sec

2. Unpolarized light of intensity I_0 falls on a combination of two linear polarizers where the second polarizer is having its axis rotated clockwise by 30° with respect to the first. The transmitted intensity will be:
(a) $3I_0/4$ (b) $3I_0/8$ (c) $\sqrt{3}I_0/4$ (d) $I_0/4$

3. A left circularly polarized light beam of wavelenfth 600 nm is incident on a crystal of thickness d and propagates perpendicular to its optic axis. The ordinary and extraordinary refractive indices of the crystal are $n_o = 1.54$ and $n_e = 1.55$ respectively. The emergent light will be right circularly polarized if d is :
(a) 120 μm (b) 60 μm (c) 30 μm (d) 15 μm

4. In a two beam interference pattern the maximum and minimum intensity values are found to be 25 I_0 and 9 I_0 respectively, where I_0 is a constant. The intensities of the two interfering beam are
(a) 16 I_0 and I_0 (b) 5 I_0 and 3 I_0 (c) 17 I_0 and 8 I_0 (d) 8 I_0 and 2 I_0

5. A parallel beam of infrared radiation of wavelength of 1.01×10^{-6} m is incident normally on a screen with two slits 5×10^{-6} m apart and the resulting interference pattern is observed on a distant screen. What is the largest number of maxima that can be observed on the screen?
(a) 4 (b) 9 (c) 13 (d) infinitely many

6. An atom emits a photon of wavelength $\lambda = 600$ nm by transition from an excited state of life time 8×10^{-9}s. If $\Delta\upsilon$ represents the minimum uncertainty in the frequency of the photon, the fractional width $\frac{\Delta\upsilon}{\upsilon}$ of the spectral line is of the order of
(a) 10^{-4} (b) 10^{-6} (c) 10^{-8} (d) 10^{-10}

7. The lietime of an atomic state is 1 nanosecond. The Natural line widht of the spectral line in the emission spectrum of this state is of the order of
(a) 10^{-10} *eV* (b) 10^{-9} *eV* (c) 10^{-6} *eV* (d) 10^{-4} *eV*

8. When light is emitted from a gas of excited atoms, the lines in the spectrum are Doppler-broadened due to the thermal motion of the emitting atoms.
The Doppler width of an emission line of wavelength 500 nanometres (nm) emitted by an excited atom of Argon $\left({}^{40}_{20}A\right)$ at room temperature $(27°C)$ can be estimated as
(a) 5.8×10^{-4} nm (b) 3.2×10^{-4} nm (c) 3.2×10^{-3} nm (d) 2.5×10^{-3} nm

9. A sodium atom in the first excited 3P state has a lifetime of 16 ns for decaying to the ground 3S state. The wavelength of the emitted photon is 589 nm. The corresponding linewidth of the transition (in frequency units) is about
(a) 1.7×10^{6} Hz (b) 1×10^{7} Hz (c) 6.3×10^{7} Hz (d) 5×10^{14} Hz

10. The intensity of a laser in free space is 150 mW/m^2. The corresponding amplitude of the electric field of the laser is 1063 V/m. $\left(\varepsilon_0 = 8.854\times10^{-12}\ C^2/N.m^2\right)$

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ANSWER KEY

1. (a)	2. (b)	3. (c)	4. (a)	5. (a)	6. (b)	7. (c)
8. (d)	9. (a)	10. (10.58 to 10.70)				

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SUBJECT: PHYSICAL SCIENCES (NET-JRF/GATE)

SECTION: ATOMIC & MOLECULAR PHYSICS

Assignment 1: Bohr Atomic Model

1. An electron is initially in the n = 3 state and the average lifetime of this state is 10^{-8} sec. The number of revolution that the electron takes before making a transition to the n = 2 state, is
   (a) 8.2×10^{4} (b) 8.2×10^{5} (c) 8.2×10^{6} (d) 8.2×10^{7}

2. The wavelength of seventh line of the Balmer series of hydrogen atom is
   (a) 384 nm (b) 424 nm (c) 456 nm (d) 512 nm

3. The energy required to remove an electron from a singly-ionized Helium atom which in the n = 8 state, is
   (a) 0.213 eV (b) 0.51 eV (c) 0.85 eV (d) 1.11 eV

4. The momentum of the photon emitted by a hydrogen atom making a direct transition from an excited state n = 10 to the ground state, is
   (a) $2.8\times10^{-27}\,kg\,m\,s^{-1}$ (b) $7.2\times10^{-27}\,kg\,m\,s^{-1}$ (c) $7.2\times10^{-26}\,kg\,m\,s^{-1}$ (d) $2.8\times10^{-26}\,kg\,m\,s^{-1}$

5. An accelarated beam of electrons bombards a sample of hydrogen and the first line of Paschen series is emiited. The electrons must have been accelarated through a minimum potential difference of
   (a) 12.8 V (b) 14.1 V (c) 16.7 V (d) 19.1 V

6. Suppose E_H be the binding energy of hydrogen atom and E_p be the binding energy of the positronium atom which consists of a positron and an electron. Then, which of the following statements is true?
   (a) $E_p = E_H$ (b) $E_p = \frac{1}{3}E_H$ (c) $E_p = \frac{1}{2}E_H$ (d) $E_p = 2E_H$

7. Suppose λ_H be the spectral wavelength of hydrogen atom and λ_p be the spectral wavelength of the positronium atom which consists of a positron and an electron. Then, which of the following statements is true?
   (a) $\lambda_p = \lambda_H$ (b) $\lambda_p = 2\lambda_H$ (c) $\lambda_p = \frac{1}{2}\lambda_H$ (d) $\lambda_p = \frac{1}{3}\lambda_H$

A μ^- meson (Charge -e, Mass 207m_e) can be captured by a proton to form a hydrogen-like atom muonic-atom.

8. The radius of the first bohr orbit is
   (a) 0.285 pm (b) 0.345 pm (c) 0.415 pm (d) 455 pm

9. The binding energy of the atom is
   (a) 1750 eV (b) 2140 eV (c) 2530 eV (d) 3120 eV

10. The first line of the Balmer series is
    (a) 6.5 A^0 (b) 18.3 A^0 (c) 25.3 A^0 (d) 35.3 A^0

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11. A mixture of ordinary hydrogen and tritium is excited and its spectrum is studied. The shift in wavelength for the H_α lines of the two kinds of hydrogen, is
(a) 2.4 A^0 (b) 3.3 A^0 (c) 5.4 A^0 (d) 6.7 A^0

Electrons of energy 12.2 eV are fired at hydrogen atoms in a gas-discharge tube.

12. The principal quantum number of the highest state that the electron can reach, is
(a) 2 (b) 3 (c) 4 (d) 5

13. The number of transitions that the electron can make, is
(a) 1 (b) 2 (c) 3 (d) 4

14. In a transition to a state of excitation energy 10.19 eV, an hydrogen like atom emits a 4890 A^0 photon. The binding energy of the initial state is
(a) 7.66 eV (b) 8.92 eV (c) 10.19 eV (d0 13.6 eV

15. The temparature will the average molecular kinetic energy in the gaseous hydrgen be equal to the binding energy of the hydrogen atom, is
(a) $10^4 K$ (b) $10^5 K$ (c) $10^6 K$ (d) $10^7 K$

16. In the hydrogen spectrum, the ratio of the wavelengths for Lyman-α radiation to Balmer-α radiation is
(a) 5/48 (b) 1/3 (c) 5/27 (d) 3

17. The wavelength of one of the visible lines in the spectrum of the hydrogen atom is approximately 6560 A^0. It is known that this corresponds to a transition between the states with principal quantum number n = 2 and n = 3. The frequency corresponding to the transition from the ground state to the first excited state will be
(a) $4.56\times10^{14} Hz$ (b) $1.65\times10^{15} Hz$ (c) $2.47\times10^{15} Hz$ (d) $3.29\times10^{15} Hz$

18. Consider the spectral line resulting from the transition n = 2 and n = 1 in the atoms and ions given below. The shoertest wavelength will be produced by
(a) Hydrogen atom (b) Deutron atom
(c) Singly ionized helium (d) Doubly ionized lithium

19. A gas of monochromatic hydrogen is bombarded with a stream of electrons that have been accelerated from rest through a potenial difference 12.75 Volts. In the emission spectra one can observe
(a) Lymam series (b) Balmer Series (c) Paschen Series (d) Pfund Series

20. If the principal quantum number and the azimuthal quantum number in the relativistic model of the atom are 3 and 1 respectively, then the magnitude of the semi-minor axis 'b' in terms of the semi major axis 'a' is given by
(a) b = a/3 (b) b = 2a/3 (c) b = a/2 (d) b = a

ANSWER KEY

1.(b)	**2.(a)**	**3.(c)**	**4.(b)**	**5.(a)**	**6.(c)**
7.(b)	**8.(a)**	**9.(c)**	**10.(d)**	**11.(a)**	**12.(b)**
13.(c)	**14.(a)**	**15.(b)**	**16.(c)**	**17.(c)**	**18.(d)**
19.(d)	**20.(a)**				

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Subject: PHYSICAL SCIENCES (NET-JRF/GATE)

Section: ATOMIC & MOLECULAR PHYSICS

Assignment 2: Vector atom model, Spin-orbit Interaction, Helium spectra

1. The two possible orientations of $\vec{S}$ with respect to an external magnetic field $\vec{B}$ along z-axis, are

   (a) $\cos^{-1}\left(\pm\frac{1}{\sqrt{2}}\right)$ (b) $\cos^{-1}\left(\pm\frac{1}{\sqrt{3}}\right)$ (c) $\cos^{-1}\left(\pm\frac{1}{3}\right)$ (d) $\cos^{-1}\left(\pm\frac{1}{2}\right)$

2. The magnitude of magnetic dipole moment corresponding to spin of an electron is

   (a) μ_B (b) $2\mu_B$ (c) $\sqrt{2}\mu_B$ (d) $\sqrt{3}\mu_B$

3. A beam of electrons (each of rest mass m, charge e) enters in a uniform magnetic field B along z-axis. The energy separation between the electrons having spin parallel and anti-parallel with magnetic field, is

   (a) $\frac{eB\hbar}{m}$ (b) $\frac{eB\hbar}{2m}$ (c) $\frac{eB\hbar}{4m}$ (d) 0

4. The number of possible spectroscopic terms of a one electron atom corresponding to n = 4 is

   (a) 3 (b) 5 (c) 7 (d) 9

5. The angle between the orbital angular momentum and spin angular momentum for the term $^2D_{3/2}$ is

   (a) 45^0 (b) 62^0 (c) 90^0 (d) 135^0

6. Which of the following spectroscopic term is not allowed?

   (a) $^2D_{3/2}$ (b) $^2F_{5/2}$ (c) $^2P_{3/2}$ (d) $^2D_{1/2}$

7. Consider the state in which $l=4, s=1/2$. The orientation of total angular momentum w.r.t z-axis for the state with largest possible j, m_j, is

   (a) 25.2^0 (b) 39.8^0 (c) 51.2^0 (d) 74.8^0

8. Which of the following statements is CORRECT?
   The difference of spin-orbit correction to energy between the spin-down and spin-up electron in a hydrogen like atom will
   (a) increase with increase in atomic number.
   (b) decrease with the principal quantum number
   (c) increase with principal quantum number
   (d) decrease with orbital quantum number

9. In the quantum mechanical relativistic correction to energy of an electron in a hydrogen like atom, the change in the hamiltonian corresponding to relativity is

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(a) $\frac{p^4}{8m_0^3c^2}$ (b) $-\frac{p^4}{8m_0^3c^2}$ (c) $-\frac{p^4}{16m_0^3c^2}$ (d) $-\frac{p^4}{4m_0^3c^2}$

10. The number of allowed transitions in the fine structure of H_α line is

(a) 3 (b) 4 (c) 5 (d) 6

11. Find the gound state term of the following atoms:

(i) $^{14}_{7}N$ (ii) $^{12}_{6}C$ (iii) $^{16}_{8}O$ (iv) $^{24}_{11}Na$ (v) C^* (vi) Na^*

The electronic configuration of $_{25}Mn$ atom is $1s^2 2s^2 2p^6 3s^2 3p^6 3d^5 4s^2$.

12. The ground state term of Mn atom will be

(a) $^6S_{5/2}$ (b) $^6P_{5/2}$ (c) $^1S_0$ (d) $^3P_0$

13. The ground state term of Mn^{3+} ion will be

(a) $^5D_0$ (b) $^5D_4$ (c) $^6S_{5/2}$ (d) $^6P_{5/2}$

14. How does the total angular quantum number J change in the transition $Cr\left(3d^6\right)$ atom ionizes to $Cr^{2+}\left(3d^4\right)$?

(a) Increases by 2 (b) Decreases by 2 (c) Decreases by 4 (d) Does not change

15. If the doublet splitting of the first excited state $2^2D_{5/2} - 2^2D_{3/2}$ of He^+ is 3.67 cm^{-1}, then the corresponding separation of H atom is

(a) 0.23 cm^{-1} (b) 0.36 cm^{-1} (c) 0.52 cm^{-1} (d) 0.76 cm^{-1}

16. Which of the following is true for the correction to energy in the estimation of the ground state energy of the following atoms due to coloumbian interactions between electrons?

(a) $\Delta E_{He} < \Delta E_{Li^+} < \Delta E_{Be^{++}} < \Delta E_{B^{+++}}$ (b) $\Delta E_{He} > \Delta E_{Li^+} > \Delta E_{Be^{++}} > \Delta E_{B^{+++}}$

(c) $\Delta E_{He} = \Delta E_{Li^+} > \Delta E_{Be^{++}} > \Delta E_{B^{+++}}$ (d) $\Delta E_{He} > \Delta E_{Li^+} > \Delta E_{Be^{++}} = \Delta E_{B^{+++}}$

17. Why triplet energy states lie lower than the singlet energy states in He atom?

18. Why 1^1S_0 is not the ground state of orthohelium?

19. Why 2^3S_1 and 2^1S_0 states in Helium are highly metastable?

20. The spin-orbit interaction in an atom is given by $H = a\vec{L}.\vec{S}$, where $\vec{L}$ and $\vec{S}$ denote the orbital and spin angular momenta respectively, of the electron. The splitting between the levels $^2P_{3/2}$ and $^2P_{1/2}$ is

(a) $\frac{3}{2}a\hbar^2$ (b) $\frac{1}{2}a\hbar^2$ (c) $3a\hbar^2$ (d) $\frac{5}{2}a\hbar^2$

ANSWER KEY

1.(b)	**2.(d)**	**3.(a)**	**4.(c)**	**5.(d)**	**6.(d)**
7.(a)	**8.(c)**	**9.(b)**	**10.(c)**	**12.(a)**	**13.(a)**
14.(c)	**15.(a)**	**16.(b)**	**20.( )**		

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SUBJECT: PHYSICAL SCIENCES (NET-JRF/GATE)

SECTION: ATOMIC & MOLECULAR PHYSICS

Assignment 4: Rotational Spectra

Common Data Questions Q.1 and Q.2

The $J=0 \rightarrow J=1$ absorption line in CO occurs at a frequency of $1.153\times10^{11}\,s^{-1}$.

(Given: The reduced mass of CO molecule is $1.14\times10^{-26}\,kg$)

1. The moment of inertia of CO molecule is

(a) $0.8\times10^{-46}\,kg-m^2$ (b) $1.5\times10^{-46}\,kg-m^2$ (c) $0.8\times10^{-42}\,kg-m^2$ (d) $1.5\times10^{-42}\,kg-m^2$

2. The internuclear separation of CO molecule is

(a) $0.48A^0$ (b) $0.84A^0$ (c) $1.15A^0$ (d) $1.95A^0$

3. The $J=0 \rightarrow J=1$ transition line occurs at a frequency of $1.153\times10^{11}\,s^{-1}$ in $^{12}C^{16}O$ and at a frequency of $1.102\times10^{11}\,s^{-1}$ in $^{?}C^{16}O$. The mass number of the unknown isotope of carbon is

(a) 13 (b) 14 (c) 15 (d) 16

Common Data Questions Q.4, Q.5 and Q.6

The separation of lines in the far infra red spectrum of HCl is 20.68 cm^{-1}.

(Given: The reduced mass of HCl molecule is $1.62\times10^{-27}\,kg$)

4. The $J=14 \rightarrow J=15$ transition occurs at

(a) $103.4\,cm^{-1}$ (b) $206.8\,cm^{-1}$ (c) $310.2\,cm^{-1}$ (d) $413.6\,cm^{-1}$

5. The moment of inertia of the HCl molecule is

(a) $1.34\times10^{-40}\,kg-m^2$ (b) $2.7\times10^{-40}\,kg-m^2$ (c) $1.34\times10^{-47}\,kg-m^2$ (d) $2.7\times10^{-47}\,kg-m^2$

6. The internuclear distance of HCl molecule is

(a) $0.48A^0$ (b) $0.84A^0$ (c) $1.30A^0$ (d) $1.95A^0$

7. The wave numbers of the lines in a band are given by

$$\nu = 1000(2n-1) \quad \text{for positive } 'n'$$
$$= -1000(2n-1) \quad \text{for negative } 'n'$$

The moment of inertia of the emitter molecule of the spectrum is

(a) $2.8\times10^{-49}\,kg-m^2$ (b) $5.6\times10^{-49}\,kg-m^2$ (c) $8.4\times10^{-49}\,kg-m^2$ (d) $11.2\times10^{-49}\,kg-m^2$

8. The rotational inertia of H_2 molecule is $4.5\times10^{-48}\,kg-m^2$. The temparature at which the average kinetic translational kinetic energy of an H_2 molecule will be equal to energy difference between the ground rotational state and the first excited rotational state, will be

(a) 60 K (b) 120 K (c) 180 K (d) 240 K

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9. Which one of the following molecule does not exhibit rotational spectra?

(a) CCl_4 (b) HF (c) HBr (d) O_2

10. The moment of inertia of a rigid diatomic molecule A is 6 times that of another rigid diatomic molecule B. If the rotational energies of the molecules are equal, then the corresponding values of the roational quantum numbers J_A and J_B are

(a) $J_A = 2, J_B = 1$ (b) $J_A = 3, J_B = 1$ (c) $J_A = 5, J_B = 0$ (d) $J_A = 6, J_B = 1$

ANSWER KEY

1. (b) **2. (c)** **3. (a)** **4. (c)** **5. (d)** **6. (c)**

7. (a) **8. (b)** **9. (d)** **10. (b)**

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SECTION: ATOMIC & MOLECULAR PHYSICS

Assignment 5: Vibrational Spectra & Raman Spectra

Common Data Questions Q.1, Q. 2 and Q. 3

The force constant of the bond in CO molecule is 1870 Nm^{-1}.

(Given: The reduced mass of CO molecule is $1.14\times10^{-26}kg$)

1. The frequncy of vibration of the CO molecule is

(a) $6.45\times10^{13}s^{-1}$ (b) $9.45\times10^{13}s^{-1}$ (c) $9.45\times10^{11}s^{-1}$ (d) $6.45\times10^{11}s^{-1}$

2. The energy of lowest vibartional level of CO molecule is

(a) 0.07 eV (b) 0.13 eV (c) 0.26 eV (d) 0.39 eV

3. The spacing between the vibrational enrgy levels of CO molecule is

(a) 0.07 eV (b) 0.13 eV (c) 0.26 eV (d) 0.39 eV

4. The force constant of the vibrating HCl molecule is 480 Nm^{-1}. The amplitude of vibration of HCl molecule in the first excited vibrational level will be

(Given: The reduced mass of HCl molecule is $1.62\times10^{-27}kg$)

(a) 0.19 A^0 (b) 0.28 A^0 (c) 0.42 A^0 (d) 0.59 A^0

5. The vibrational frequency and the anharmonicity constant of HD molecule are 3817 cm^{-1} and 95 cm^{-1} respectively. The zero point energy of HD molecule in the units of kcal/mole, is

(Given: 1 $cm^{-1} = 2.858\times10^{-3}$ kcal/mole)

(a) 1.25 (b) 2.47 (c) 3.39 (d) 5.39

Common Data Questions Q. 4 and Q. 5

The fundamental band and the first overtone for CO molecule is centered at 2143.3 cm^{-1} and 4259.7 cm^{-1} respectively. (Given: The reduced mass of CO molecule is $1.14\times10^{-26}kg$)

6. The vibrational frequency of CO molecule is

(a) 2170 cm^{-1} (b) 2467 cm^{-1} (c) 1108 cm^{-1} (d) 3456 cm^{-1}

7. The anharmonicity constant of CO molecule will be

(a) 6.8 cm^{-1} (b) 10.2 cm^{-1} (c) 13.5 cm^{-1} (d) 19.5 cm^{-1}

8. The fundamental mode of HCl occurs at 2886 cm^{-1}. The fundamental mode of DCl will occur

(a) 1367 cm^{-1} (b) 2069 cm^{-1} (c) 2778 cm^{-1} (d) 3024 cm^{-1}

9. The moment of inertia of the HCl^{35} molecule in the $v=0$ and $v=1$ levels is $20.8\times10^{-7}kg-m^2$. The wave number difference between the $R(0)$ and $P(1)$ lines of the fundamemtal band for HCl^{35} molecule is

(a) 4164 m^{-1} (b) 1041 m^{-1} (c) 2082 m^{-1} (d) 5205 m^{-1}

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10. In an experiment, the exciting line of of a sample is observed at 5460 A^0 and stokes line is ob served at 5520 A^0. The wavelength of the anti-stokes line is

(a) 5420 A^0 (b) 5401 A^0 (c) 5380 A^0 (d) 5580 A^0

11. In th vibrational Raman spectrum of HF molecule, the Raman lines are observed at wavelengths 2670 A^0 and 3430 A^0 respectively. The fundamental vibrational frequency of the molecule is

(a) $0.62\times10^{14}\ Hz$ (b) $1.02\times10^{14}\ Hz$ (c) $1.24\times10^{14}\ Hz$ (d) $1.62\times10^{14}\ Hz$

12. In the Rotational Raman spectrum of *HCl* molecule, the displacemnts from the exciting line are represented by

$$\Delta\bar{\nu}=\pm(120+80J)\ cm^{-1}$$

The moment of inertia of the molecule is

(a) $1.4\times10^{-27}\ kg-m^2$ (b) $2.8\times10^{-27}\ kg-m^2$

(c) $4.2\times10^{-27}\ kg-m^2$ (d) $5.6\times10^{-27}\ kg-m^2$

ANSWER KEY

1.(a)	**2.(b)**	**3.(c)**	**4.(a)**	**5.(d)**	**6.(a)**	**7.(c)**
8.(b)	**9.(a)**	**10.(b)**	**11.(c)**	**12.(d)**		

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